Du, Youwu; **Cao, Weihua**; **She, Jinhua**; **Wu, Min**; **Fang, Mingxing**

Disturbance rejection via feedforward compensation using an enhanced equivalent-input-disturbance approach. (English) Zbl 1450.93011

J. Franklin Inst. 357, No. 15, 10977-10996 (2020).

Summary: This paper presents an enhanced equivalent-input-disturbance (EID) approach that provides an additional degree of freedom to reject an exogenous disturbance for a control system. The EID approach uses a state observer and an estimator to calculate an equivalent disturbance on the control input channel for feedforward compensation. However, there is a constraint on the design of the state observer in an EID-based control system. This imposes a limitation on control performance. A high-gain observer (HGO) is employed to remove the constraint. This increases the flexibility of system design and improves disturbance-rejection performance. The convergence of the HGO is analyzed and the system is separated into two subsystems for stability analysis and design. A numerical example is used to show the validity of the method. The simulation results show that the disturbance is mainly rejected by feedforward compensation rather than feedback control.

MSC:

93B35 Sensitivity (robustness)
93B53 Observers
93D05 Lyapunov and other classical stabilities (Lagrange, Poisson, L^p, l^p, etc.) in control theory

Keywords:

equivalent-input-disturbance approach; high-gain observer; stability

Full Text: DOI

References:

[1] Gao, Z., On the centrality of disturbance rejection in automatic control, ISA Trans., 53, 4, 850-857 (2014)

[2] Chen, X.; Zhao, H.; Sun, H.; Zhen, S.; Huang, K., A novel adaptive robust control approach for underactuated mobile robot, J. Frankl. Inst., 356, 5, 2474-2490 (2019) · Zbl 1411.93099

[3] Skoczowski, S.; Domek, S.; Pietrusewicz, K.; Broel-Plater, B., A method for improving the robustness of PID control, IEEE Trans. Ind. Electron., 52, 6, 1669-1676 (2005)

[4] Ruderman, M.; Ruderman, A.; Bertram, T., Observer-based compensation of additive periodic torque disturbances in permanent magnet motors, IEEE Trans. Ind. Inf., 9, 2, 1130-1138 (2013)

[5] Santos, T. L.M.; Franklin, T. S., Enhanced finite spectrum assignment with disturbance compensation for LTI systems with input delay, J. Frankl. Inst., 355, 8, 3541-3566 (2018) · Zbl 1390.93339

[6] Bao, Y.; Wang, L. Y.; Wang, C.; Jiang, J.; Jiang, C.; Duan, C., Adaptive feedforward compensation for voltage source disturbance rejection in DC-DC converters, IEEE Trans. Control Syst. Technol., 26, 1, 344-351 (2018)

[7] Chen, W. H.; Yang, J.; Guo, L.; Li, S., Disturbance-observer-based control and related methods- an overview, IEEE Trans. Ind. Electron., 63, 2, 1083-1095 (2016)

[8] Sariyildiz, E.; Oboe, R.; Ohnishi, K., Disturbance observer-based robust control and its applications: 35th anniversary overview, IEEE Trans. Ind. Electron., 67, 3, 2042-2053 (2020)

[9] Yang, G.; Yao, J., Output feedback control of electro-hydraulic servo actuators with matched and mismatched disturbances rejection, J. Frankl. Inst., 356, 16, 9152-9179 (2019) · Zbl 1423.93132

[10] Chen, X. S.; Yang, J.; Li, S. H.; Li, Q., Disturbance observer based multi-variable control of ball mill grinding circuits, J. Process Control, 19, 7, 1205-1213 (2009)

[11] Rubio, J. J., Structure control for the disturbance rejection in two electromechanical processes, J. Frankl. Inst., 353, 14, 3610-3631 (2016) · Zbl 1347.93115

[12] An, H.; Liu, J.; Wang, C.; Wu, L., Disturbance observer-based antiwindup control for air-breathing hypersonic vehicles, IEEE Trans. Ind. Electron., 63, 5, 3038-3049 (2016)

[13] Sanz, R.; Garcia, P.; Zhong, Q. C.; Albertos, P., Predictor-based control of a class of time-delay systems and its application to quadrotors, IEEE Trans. Ind. Electron., 64, 1, 459-469 (2017)

[14] Amin, R. U.; Inayat, I.; Ai Jun, L., Finite time position and heading tracking control of coaxial octorotor based on extended inverse multi-quadratic radial basis function network and external disturbance observer, J. Frankl. Inst., 356, 8, 4240-4269 (2019) · Zbl 1412.93018

[15] Tokyo, Japan

[16] Chen, W. H.; Ballance, D. J.; Gawthrop, P. J.; O'Reilly, J., A nonlinear disturbance observer for robotic manipulators, IEEE Trans. Ind. Electron., 47, 4, 932-938 (2000)

[17] Chen, W.-H., Disturbance observer based control for nonlinear systems, IEEE/ASME Trans. Mechatron., 9, 4, 706-710 (2004)

[18] Li, S.; Yang, J.; Chen, W.-H.; Chen, X., Disturbance Observer-Based Control: Methods and Applications (2014), CRC Press: CRC Press Boca Raton, FL

[19] Zhang, L.; Wei, X.; Zhang, H., Disturbance observer-based elegant anti-disturbance control for stochastic systems with multiple disturbances, Asian J. Control, 20, 1, 1-11 (2018)

[20] Wei, X.-J.; Wu, Z.-J.; Karimi, H. R., Disturbance observer-based disturbance attenuation control for a class of stochastic systems, Automatica, 63, 21-25 (2016) · Zbl 1329.93129

[21] Kim, K.; Rew, K.; Kim, S., Disturbance observer for estimating higher order disturbances in time series expansion, IEEE Trans. Autom. Control, 55, 8, 1905-1911 (2010) · Zbl 1368.93123

[22] Yang, J.; Chen, W.-H.; Li, S., Non-linear disturbance observer-based robust control for systems with mismatched disturbances/uncertainties, IET Control Theory Appl., 5, 18, 2053-2062 (2011)

[23] Wei, X. J.; Guo, L., Composite disturbance-observer-based control and H_⊠ control for complex continuous models, Int. J. Robust Nonlinear Control, 20, 1, 106-118 (2010) · Zbl 1191.93014

[24] Guo, L.; Wen, X.-Y., Hierarchical anti-disturbance adaptive control for non-linear systems with composite disturbances and applications to missile systems, Trans. Inst. Meas. Control, 33, 8, 942-956 (2010)

[25] Zhang, H.; Wei, X.; Karimi, H. R.; Han, J., Anti-disturbance control based on disturbance observer for nonlinear systems with bounded disturbances, J. Frankl. Inst., 355, 12, 4916-4930 (2018) · Zbl 1395.93264

[26] Han, J., From PID to active disturbance rejection control, IEEE Trans. Ind. Electron., 56, 3, 900-906 (2009)

[27] Ma, X.; Guo, Y.; Chen, L., Active disturbance rejection control for electric power steering system with assist motor variable mode, J. Frankl. Inst., 355, 3, 1139-1155 (2018) · Zbl 1393.93037

[28] Zhou, R.; Tan, W., Analysis and tuning of general linear active disturbance rejection controllers, IEEE Trans. Ind. Electron., 66, 7, 5497-5507 (2019)

[29] Huang, Y.; Xue, W., Active disturbance rejection control: methodology and theoretical analysis, ISA Trans., 53, 4, 963-976 (2014)

[30] Madonski, R.; Herman, P., Survey on methods of increasing the efficiency of extended state disturbance observers, ISA Trans., 56, 18-27 (2015)

[31] She, J.; Xin, X.; Ohyama, Y., Estimation of equivalent input disturbance improves vehicular steering control, IEEE Trans. Veh. Technol., 56, 6, 3722-3731 (2007)

[32] She, J. H.; Fang, M.; Ohyama, Y.; Hashimoto, H.; Wu, M., Improving disturbance-rejection performance based on an equivalent-input-disturbance approach, IEEE Trans. Ind. Electron., 55, 1, 380-389 (2008)

[33] Hunt, L. R.; Meyer, G.; Su, R., Noncausal inverses for linear systems, IEEE Trans. Autom. Control, 41, 4, 608-611 (1996) · Zbl 0864.93055

[34] She, J. H.; Xin, X.; Pan, Y., Equivalent-input-disturbance approach-analysis and application to disturbance rejection in dual-stage feed drive control system, IEEE/ASME Trans. Mechatron., 16, 2, 330-340 (2011)

[35] Liu, R. J.; Wu, M.; Liu, G. P.; She, J.; Thomas, C., Active disturbance rejection control based on an improved equivalent-input-disturbance approach, IEEE/ASME Trans. Mechatron., 18, 4, 1410-1413 (2013)

[36] Liu, R. J.; Liu, G. P.; Wu, M.; She, J.; Nie, Z. Y., Robust disturbance rejection in modified repetitive control system, Syst. Control Lett., 70, 8, 100-108 (2014) · Zbl 1290.93055

[37] Gao, F.; Wu, M.; She, J.; Cao, W., Disturbance rejection in nonlinear systems based on equivalent-input-disturbance approach, Appl. Math. Comput., 282, 5, 244-253 (2016) · Zbl 1410.93080

[38] Liu, R.; She, J.; Wu, M.; Zhu, F.; Nie, Z., Robust disturbance rejection for a fractional-order system based on equivalent-input-disturbance approach, Sci. China Inf. Sci., 61, 7, 200-211 (2018)

[39] Du, Y.; Cao, W.; She, J.; Wu, M.; Fang, M.; Kawata, S., Disturbance rejection for input-delay system using observer-predictor-based output feedback control, IEEE Trans. Ind. Inf., 16, 7, 4489-4497 (2020)

[40] Du, Y.; Cao, W.; Wu, M.; She, J.; Fang, M.; Kawata, S., Disturbance rejection and control system design using improved equivalent-input-disturbance approach, IEEE Trans. Ind. Electron., 67, 4, 3013-3023 (2020)

[41] Ho, D. W.C.; Lu, G., Robust stabilization for a class of discrete-time non-linear systems via output feedback: The unified LMI approach, Int. J. Control, 76, 2, 105-115 (2003) · Zbl 1026.93048

[42] Wu, M.; Gao, F.; Yu, P.; She, J.; Cao, W., Improve disturbance-rejection performance for an equivalent-input-disturbance-based control system by incorporating a proportional-integral observer, IEEE Trans. Ind. Electron., 67, 2, 1254-1260 (2020)

[43] Li, S.; Yang, J.; Chen, W. H.; Chen, X., Generalized extended state observer based control for systems with mismatched uncertainties, IEEE Trans. Ind. Electron., 59, 12, 4792-4802 (2012)

[44] Castillo, A.; Garcła, P.; Sanz, R.; Albertos, P., Enhanced extended state observer-based control for systems with mismatched uncertainties and disturbances, ISA Trans., 73, 1-10 (2018)

[45] Zhao, Z.-L.; Guo, B.-Z., A nonlinear extended state observer based on fractional power functions, Automatica, 81, 286-296 (2017) · Zbl 1372.93048